

CLAIMS

What is claimed is:

5 1. A method of reducing the effects in seismic data of downward propagating reflected and scattered acoustic energy travelling in a fluid medium comprising the steps of:

10 receiving pressure data representing at least the pressure in the fluid medium at a first location and a second location, the first location being in close proximity to the second location;

15 receiving vertical particle motion data representing at least the vertical particle motion of acoustic energy propagating in the fluid medium at a third location and a fourth location, the third location being in close proximity to the fourth location, and the first, second, third and fourth locations being within a spatial area;

20 calculating a plurality of spatial filter coefficients based in part on the velocity of sound in the fluid medium the density of the fluid medium and a plurality of acquisition parameters, thereby creating a spatial filter which is designed so as to be effective at separating up and down propagating acoustic energy over a range of non-vertical incidence angles in the fluid medium;

25 applying the spatial filter to the vertical particle motion data to generate filtered particle motion data;

combining the filtered particle motion data with the pressure data to generate separated pressure data, the separated pressure data having up and down propagating components separated; and

5 analysing at least part of the up or down propagating component of the separated pressure data.

2. The method of claim 1 wherein the acquisition parameters include the temporal sampling interval, the
10 spatial sampling interval, and the number of independent locations at which the pressure and vertical particle motion data are measured.

3. The method of claim 1 wherein the vertical
15 particle motion data is measured using one or more multi-component streamers.

4. The method of claim 1 wherein the vertical particle motion of the acoustic energy represented in said vertical particle motion data is the particle velocity of the acoustic energy.

5. The method of claim 1 wherein the vertical particle motion of the acoustic energy represented in said
25 vertical particle motion data is the vertical pressure gradient of the acoustic energy.

6. The method of claim 5 wherein the pressure gradient is measured using at least two parallel streamer cables in close proximity and vertically offset from one another.

7. The method of claim 1 wherein the vertical particle motion of the acoustic energy represented in said vertical particle motion data is the vertical displacement
5 of the acoustic energy.

8. The method of claim 1 wherein the vertical particle motion of the acoustic energy represented in said vertical particle motion data is the vertical acceleration
10 of the acoustic energy.

9. The method of claim 1 wherein the distance between the first location and the second location and the distance between the third location and the fourth location
15 is less than the Nyquist spatial sampling criterion.

10. The method of claim 9 wherein the spatial area is substantially a portion of a line, and the range of non-vertical incidence angles includes substantially all non-horizontal incidence angles within a vertical plane that
20 passes through the portion of line.

11. The method of claim 9 wherein the spatial area is a portion of a substantially planar region, and the range of non-vertical incidence angles include substantially all non-horizontal incidence angles.
25

12. A method of reducing the effects in seismic data of downward propagating reflected and scattered
30

acoustic energy travelling in a fluid medium comprising the steps of:

5

receiving pressure data representing at least the pressure in the fluid medium at a first location and a second location, the first location being in close proximity to the second location;

10

receiving vertical particle motion data representing at least the vertical particle motion of acoustic energy propagating in the fluid medium at a third location and a fourth location, the third location being in close proximity to the fourth location, and the first, second, third and fourth locations being within a spatial area;

20

calculating a plurality of spatial filter coefficients based in part on the velocity of sound in the fluid medium and the density of the fluid medium, thereby creating a spatial filter which is designed so as to be effective at separating up and down propagating acoustic energy over a range of non-horizontal incidence angles in the fluid medium;

applying the spatial filter to the pressure data to generate filtered pressure data;

25

combining the filtered pressure data with the vertical particle motion data to generate separated pressure data, the separated pressure data having up and down propagating components separated; and

30

analysing at least part of the up or down propagating component of the separated pressure data.

13. The method of claim 12 wherein the distance between the first location and the second location and the distance between the third location and the fourth location is less than the Nyquist spatial sampling criterion.

5

14. The method of claim 12 wherein the vertical particle motion data is measured using one or more multi-component streamers.

10 15. The method of claim 12 wherein the vertical particle motion of the acoustic energy represented in said vertical particle motion data is the particle velocity of the acoustic energy.

15 16. The method of claim 12 wherein the vertical particle motion of the acoustic energy represented in said vertical particle motion data is the vertical pressure gradient of the acoustic energy.

20

17. The method of claim 16 wherein the pressure gradient is measured using at least two parallel streamer cables in close proximity and vertically offset from one another.

25

18. A method of reducing the effects in seismic data of downward propagating reflected and scattered acoustic energy travelling in a fluid medium comprising the steps of:

30

receiving pressure data representing at least variations in pressure in the fluid medium at a first location, the variations caused in part by a first

source event and a second source event, the first source event and the second source event being within a spatial area;

5 receiving vertical particle motion data representing at least the vertical particle motion of acoustic energy propagating in the fluid medium at a second location, the acoustic energy being caused in part by the first source event and the second source event;

10 *Dell
Or
Bn*
15 calculating a plurality of spatial filter coefficients based in part on the velocity of sound in the fluid medium and the density of the fluid medium, thereby creating a spatial filter which is designed so as to be effective at separating up and down propagating acoustic energy from the first source event and second source event over a range of non-horizontal incidence angles in the fluid medium;

20 applying the spatial filter to the vertical particle motion data to generate filtered particle motion data;

25 combining the filtered particle motion data with the pressure data to generate separated pressure data, the separated pressure data having up and down propagating components separated; and

analysing at least part of the up or down propagating component of the separated pressure data.

19. The method of claim 18 wherein the first source event and the second source event are generated by 30 firing a seismic source at different locations at different times, and the distance between the location of the first

source event and the location of the second source event is less than the Nyquist spatial sampling criterion.

20. The method of claim 18 wherein the vertical
5 particle motion data is measured using one or more multi-
component streamers.

21. The method of claim 18 wherein the vertical
10 particle motion of the acoustic energy represented in said
vertical particle motion data is the particle velocity of
the acoustic energy.

22. The method of claim 18 wherein the vertical
15 particle motion of the acoustic energy represented in said
vertical particle motion data is the vertical pressure
gradient of the acoustic energy.

23. The method of claim 22 wherein the pressure
20 gradient is measured using at least two parallel streamer
cables in close proximity and vertically offset from one
another.

24. A computer-readable medium which can be used
for directing an apparatus to reduce the effects in seismic
25 data of downward propagating reflected and scattered
acoustic energy travelling in a fluid medium comprising:
means for retrieving pressure data
representing at least the pressure in the fluid medium
at a first location and a second location, the first
30 location being in close proximity to the second
location;

means for retrieving vertical particle motion data representing at least the vertical particle motion of acoustic energy propagating in the fluid medium at a third location and a fourth location, the third location being in close proximity to the fourth location, and the first, second, third and fourth locations being within a spatial area;

means for calculating a plurality of spatial filter coefficients based in part on the velocity of sound in the fluid medium, the density of the fluid medium and a plurality of acquisition parameters, thereby creating a spatial filter which is designed so as to be effective at separating up and down propagating acoustic energy over a range of non-vertical incidence angles in the fluid medium;

means for applying the spatial filter to the vertical particle motion data to generate filtered particle motion data;

means for combining the filtered particle motion data with the pressure data to generate separated pressure data, the separated pressure data having up and down propagating components separated; and

means for analysing at least part of the up or down propagating component of the separated pressure data.

25. The computer-readable medium of claim 24 wherein the distance between the first location and the second location and the distance between the third location

and the fourth location is less than the Nyquist spatial sampling criterion.

26. The computer-readable medium of claim 24
5 wherein the vertical particle motion data is measured using one or more multi-component streamers.

27. The computer-readable medium of claim 24
10 wherein the vertical particle motion of the acoustic energy represented in said vertical particle motion data is the particle velocity of the acoustic energy.

28. The computer-readable medium of claim 24
15 wherein the vertical particle motion of the acoustic energy represented in said vertical particle motion data is the vertical pressure gradient of the acoustic energy.

29. The computer-readable medium of claim 28
20 wherein the pressure gradient is measured using at least two parallel streamer cables in close proximity and vertically offset from one another.